Uncertainty Analysis in New Seismic Hazard Study of Spain Aimed at the Revision of the Spanish Building Code

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SUMMARY

In this paper we present a global overview of the recent study carried out in Spain for the new hazard map, which final goal is the revision of the Building Code in our country (NCSE-02). The study was carried our for a working group joining experts from The Instituto Geografico Nacional (IGN) and the Technical University of Madrid (UPM) , being the different phases of the work supervised by an expert Committee integrated by national experts from public institutions involved in subject of seismic hazard.

The PSHA method (Probabilistic Seismic Hazard Assessment) has been followed, quantifying the epistemic uncertainties through a logic tree and the aleatory ones linked to variability of parameters by means of probability density functions and Monte Carlo simulations.

In a first phase, the inputs have been prepared, which essentially are: 1) a project catalogue update and homogenization at Mw 2) proposal of zoning models and source characterization 3) calibration of Ground Motion Prediction Equations (GMPE's) with actual data and development of a local model with data collected in Spain for Mw < 5.5.

In a second phase, a sensitivity analysis of the different input options on hazard results has been carried out in order to have criteria for defining the branches of the logic tree and their weights. Finally, the hazard estimation was done with the logic tree shown in figure 1, including nodes for quantifying uncertainties corresponding to: 1) method for estimation of hazard (zoning and zoneless); 2) zoning models, 3) GMPE combinations used and 4) regression method for estimation of source parameters.

In addition, the aleatory uncertainties corresponding to the magnitude of the events, recurrence parameters and maximum magnitude for each zone have been also considered including probability density functions and Monte Carlo simulations

The main conclusions of the study are presented here, together with the obtained results in terms of PGA and other spectral accelerations SA (T) for return periods of 475, 975 and 2475 years. The map of the coefficient of variation (COV) are also represented to give an idea of the zones where the dispersion among results are the highest and the zones where the results are robust.

Table summarising the uncertainties related to input data and methods:

Variables	Choices	Treatment of uncertainty
Uncertainty on earthquake magnitude	Mw ±σMw	Aleatory uncertainty Monte Carlo
Maximum magnitude of each zone	Maximum observed magnitude Maximum magnitude from geological studies	Aleatory uncertainty Distribution function
Different seismic area source models	NCSE-02 García-Mayordomo et al, 2012 ByA	Epistemic uncertainty Logic tree
Gutenberg-Richter adjustment method	Ordinary Least Squares (OLS) Maximum Likelihood (ML)	Epistemic uncertainty Logic tree

ANALYSIS OF UNCERTAINTIES

Catalog

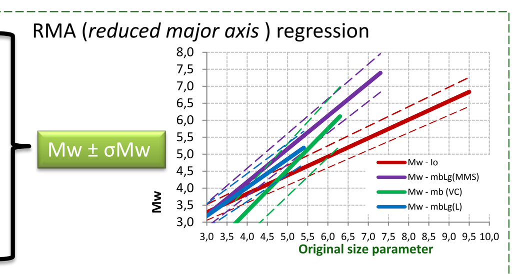
The seismic catalog of the project is homogenised to moment magnitude M_w by applying correlations between different earthquake size parameters (I, m_{bLg}, etc) and M_w. The uncertainty on the original size parameter of each record is propagated to the final M_w estimate, which incorporates an uncertainty σ_w .

HOMOGENISATION:

Original size parameter (and uncertainty):
Intensity (EMS) ± σInt
mD ± σmD
MbLg (MMS) ± σ MbLg (MMS)
MbLg(L) ± σ MbLg (L)
mb ± σmb
Mw ± σMw

Mw ± σMw

RMA (*reduced major axis*) regression



ERROR PROPAGATION:

$$yi = a + b \cdot xi$$

$x_i \pm \sigma_x ; \alpha \pm \sigma_\alpha ; \beta \pm \sigma_\beta ; \sigma_{\alpha\beta}$ → $y_i \pm \sigma_y$

$$\sigma {y_i}^2 = \left(\frac{\partial y}{\partial x}\sigma x_i\right)^2 + \left(\frac{\partial y}{\partial \alpha}\sigma \alpha_j\right)^2 + \left(\frac{\partial y}{\partial \beta}\sigma \beta_j\right)^2 + 2\frac{\partial y}{\partial \alpha}\frac{\partial y}{\partial \beta}\sigma\alpha\beta_j$$

Uncertainty on original data:

I_0 -IGN (A,B,C)	σ(0.5, 1.0, 1.5)
I_0 -IGC (1,2)	σ(0.5, 1.0)
m_D	σ(0.4)
m_{bLg}(MMS)	σ (0.3(<1985); 0.2(>1985))
m_b(VC)	σ(0.2)
m_{bLg}(L)	σ(0.2)
M_w(IGN)	σ(0.1)
M_w (IAG)	σ(0.1)
M_w specific study	case specific

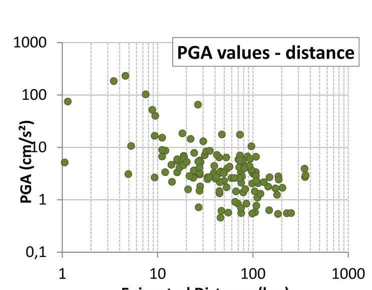
→ $M_{Wi} \pm \sigma_{MWi}$

The uncertainty associated to the original data are modeled by a triangular distribution, which width is estimated by expert judgement giving lesser uncertainty to more size modern estimates.

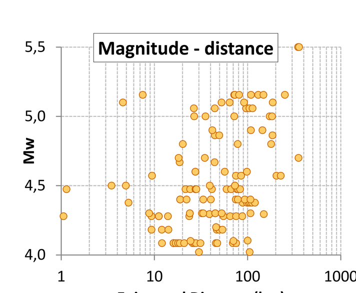
Ground motion prediction equations (GMPE)

Records contained in the IGN strong motion database are used to develop a GMPE specifically for the Iberian Peninsula. As these data only cover the small magnitude range (Mw < 5.0), other GMPE suitable for large magnitude events are considered. The statistical test of Scherbaum et al. 2004 (applied to foreign GMPE and local IGN data) and the experts considerations included in the SHARE and GEM projects are used to infer the most adequate models for M> 5.
The different models are combined to cover the complete magnitude and distance ranges required by the hazard analysis.

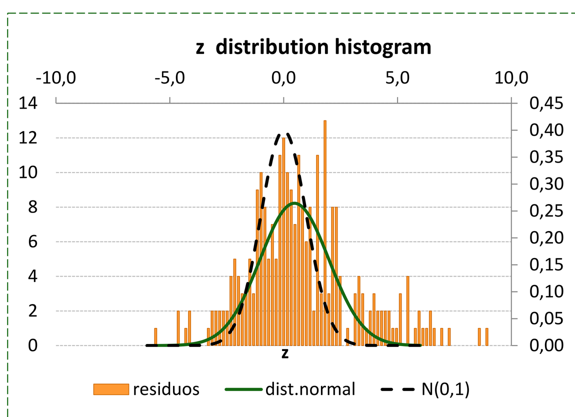
STRONG MOTION DATABASE CHARACTERISTICS



***PGA values** distribution as a function of source-to-site **distance** for the available records.*



*Earthquake **magnitude** vs. source-to-site **distance** distribution for the available records*



Example of the analysis of residuals performed for all candidate GMPE and the IGN strong motion database.

GENERAL APPROACH

APPLICATION AREA	MAGNITUDE RANGE	CHARACTERISTICS OF THE MODELS	SELECTED MODELS
Iberian Peninsula and northern Africa	M< 5.0 (4.0 – 5.0)	GMPE for low magnitudes Own GMPE	RUIZ ET AL, 2011 (MP11) BINDI ET AL, 2011(Bin11) TAPIA ET AL, 2006 (tp06)
	M> 5.0 (5.0 – 7.5)	GMPE developed for other areas	BOORE & ATKINSON 2008, AB2011 (BA08) COTTON ET AL 2008 (CT08) AKKAR & BOMMER 2010 (AB10) CAUZZI & FACCIOLI 2008 (CF08)
SW S. Vincent Cape	4.0 – 8.5	Çlow attenuation area, Models suitable for long distances and Models suitable for high magnitudes	YOUNGS ET AL 1997 (Y97) ZHAO ET AL (Z06)
Deep sources	4.0 – 6.5	Models with hypocentral distance as independent variable	

Uncertainty on Mmax assigned to each area source

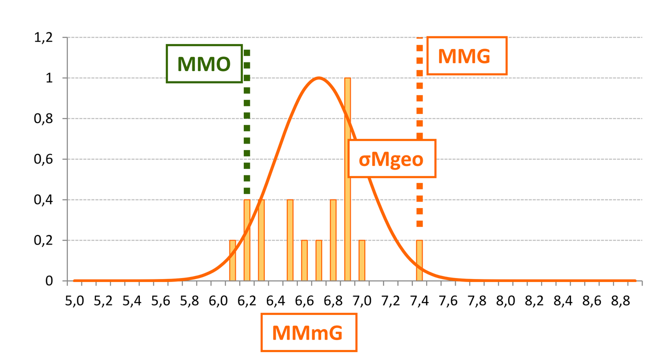
MMO = Maximum magnitude observed in the catalog
σ Mobs = Uncertainty of maximum magnitude observed in the catalog

MMmG = Maximum magnitude measured on geological studies
σMgeo = Uncertainty of maximum magnitude measured on geological studies
MMG = Maximum magnitude expected from geological studies

The types of zones distinguished, depending on the geological information available:

- **Geological zone**: the available geological information is sufficient to determine a distribution of maximum expected magnitudes.
- **Seismological zone**: only the observed seismological data can be used constraint the parameters defining the Mmax distribution.
- **Mixed zone**: Both observed seismological and geological data are used to define the Mmax distribution.

EXAMPLE OF GEOLOGICAL ZONE: the bar diagram represents the Mmax frequency distribution derived from a population of active faults for which maximum expected magnitude estimates are available.



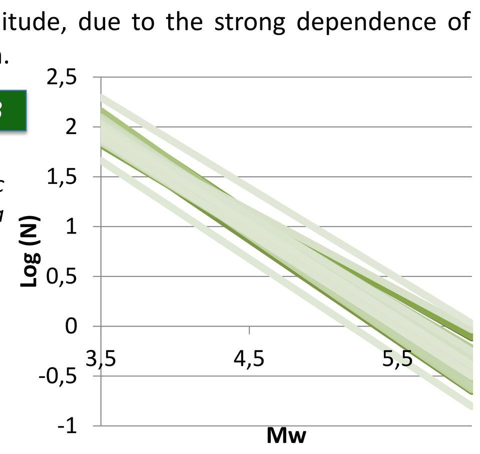
Monte Carlo simulations

-Use of Montecarlo simulations
- A triangular probability distribution function is used to characterize the uncertainty on earthquake magnitude, due to the strong dependence of the sigma value on expert opinion.

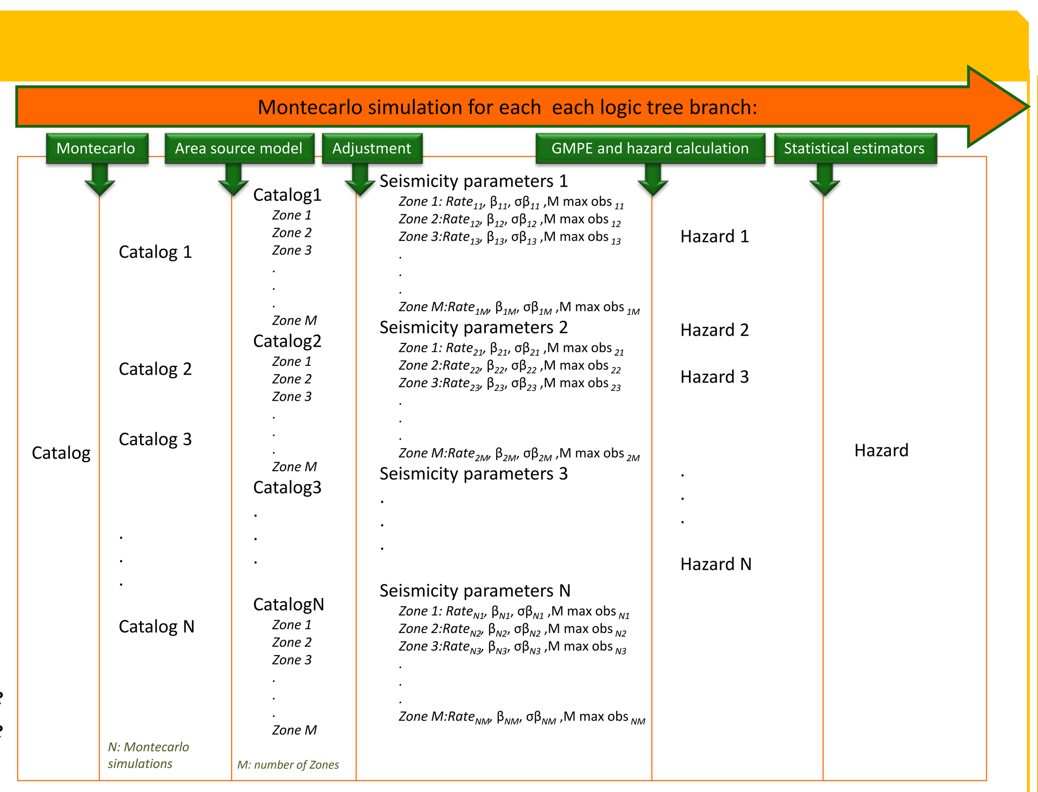
$M_{Wi} \pm \sigma_{MWi}$ → $\alpha \pm \sigma\alpha$, $\beta \pm \sigma\beta$

. σMw has an impact over seismic paramiters alfa and beta

Simulation of catalogues involves diferent simulation of sets alfa, Beta, MmAx.



The Montecarlo process will consider 100 input catalogs throughout the entire hazard calculations of each logic tree branch (in the area-source approach).

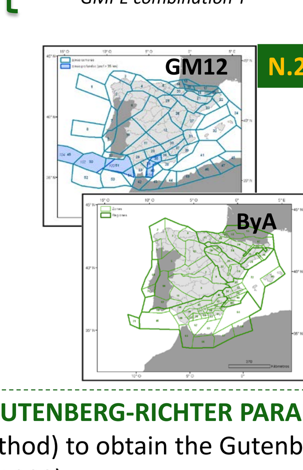


Logic tree

Peso de cada rama

Catalog — N.1
- Area source method (0.7) — N.2
  - β – Zones GM211 (0.7) — N.3: OLS (0.3), Max. Lik. (0.7) — N.4: GMPE combination 1, GMPE combination 2, ……………, GMPE combination T
  - β – regional (ByA Model) (0.3): OLS, Max. Lik.
- Zoneless method (0.3)

N.1 METHOD
Branch 1: zonation model (Cornell,1968)
Branch 2: seismicity model (Woo et al, 1996)



N.2 ZONATION
Branch 1: Big zones with significant seismicity for estimating independent b-values and Rates for each Zone. (GM12)
Branch 2: small zones: Regional b-values and rates for each zone (ByA)

N.3
ADJUSTMENT METHOD TO OBTAIN THE GUTENBERG-RICHTER PARAMETERS.
Branch 1: Ordinary Least Squares (OLS method) to obtain the Gutenberg-Richter parameters.
Branch 2: Maximum Likelihood (Weichert,1980)

N.4
GMPE: Each branch represents a combination of GMPE that cover the magnitude range required in each area source zone.

GMPEs
- Iberia N Africa
  - One model (0.4): *Cotton et al (2008)* 0.5; *Boore & Atkinson (2008)* 0.5
  - Two models (0.6)
    - M>5.0: *Akkar & Bommer (2010)* 0.7; *Cauzzi & Faccioli (2008)* 0.3
    - M<5.0: *Ruiz et al (2012)* 0.6; *Bindi et al (2011)* 0.2; *Tapia et al (2006)* 0.2
- Azores Deep: *Young et al (1997)* 0.7; *Zhao et al (2006)* 0.3

A total of **12 GMPE** are combined for the entire study area

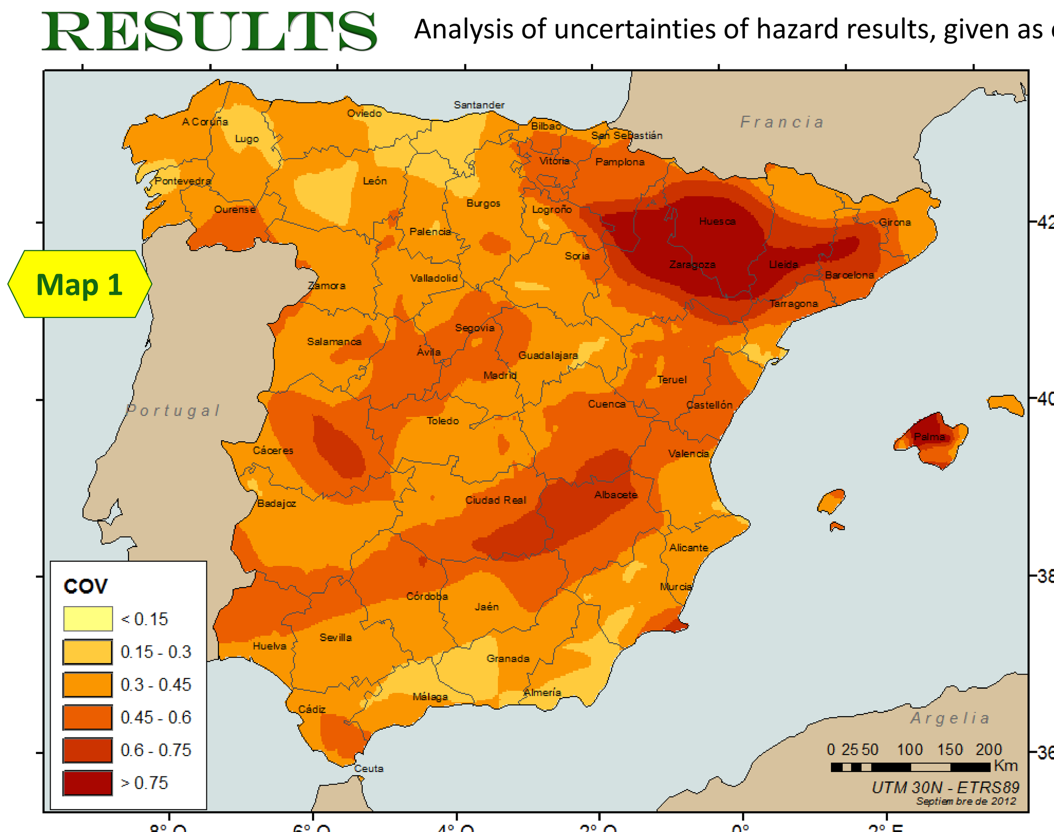
GMPE combinations

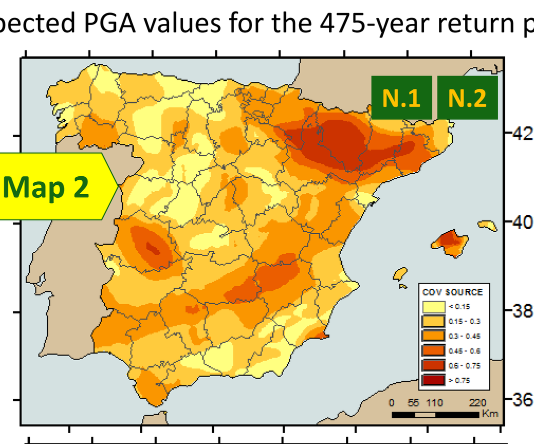
Iberian P.eninsula and N. Africa		Azores and deep sources
BA08		Y97
CT08		Y97
AB10	MP11	Y97
AB10	Bin11	Y97
AB10	TP06	Y97
CF08	MP11	Y97
CF08	Bin11	Y97
CF08	TP06	Y97
BA08		Z06
CT08		Z06
AB10	MP11	Z06
AB10	Bin11	Z06
AB10	TP06	Z06
CF08	MP11	Z06
CF08	Bin11	Z06
CF08	TP06	Z06

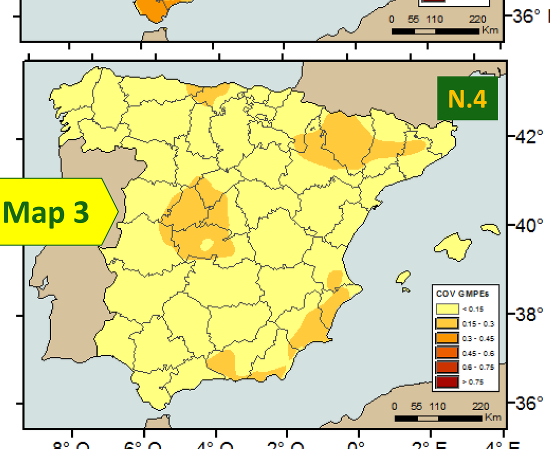
RESULTS

Analysis of uncertainties of hazard results, given as expected PGA values for the 475-year return period.

$$COV = \frac{\sigma}{\mu}$$







Map 1. Final COV map

Map 2. COV map of seismic sources (Nodes 1 and 2).

Map 3. COV map of the 9 GMPE combinations.

Map 4. Map of variability related to *Node 1* .

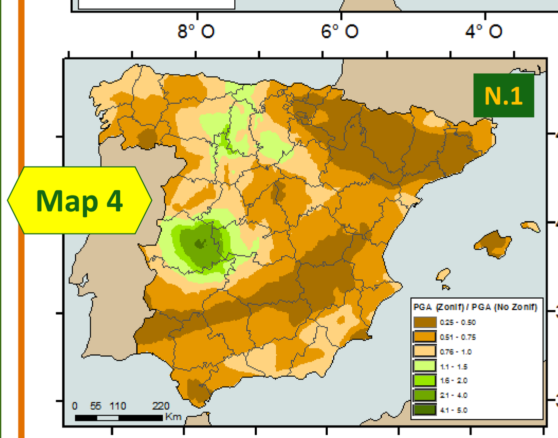
$$\frac{PGA(Area\ sources)}{PGA\ (Zoneless)}$$

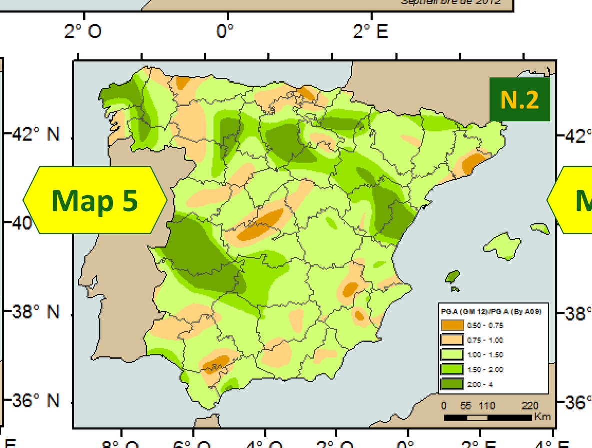
Map 5. Map of variability related to *Node 12.*

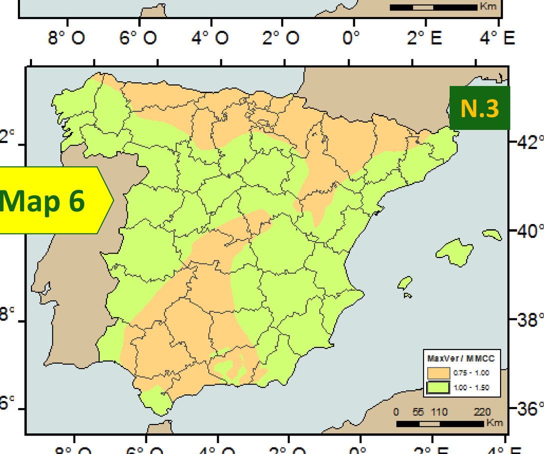
$$\frac{PGA(GM12)}{PGA\ (ByA)}$$

Map 6. Map of variability related to *Node 5.*

$$\frac{PGA(Max.Lik.)}{PGA\ (OLS)}$$







CONCLUSIONS

Sensitivity analysis of results to different branches of the logic tree shiw the impact of epistemic uncertainty on final results:

1. The uncertauinty related to method and seismic source model (nodes 1 and 2) yields more variability to results, approximately 80 % of the COV value (Map 2), than the variabliity related to GMPE combinations, which represents about 20% (Map 3).
2. The zoneless method gives higher accelerations almost accross the entire territory (Map 4).
3. The use of two are source models does not indicate a clear contribution to total variability from any of them (Map 5) .
4. The adjustment method to obtain the Gutenberg-Richter parameters (node 3) does not have a significant impact on final results (Map 6).

REFERENCES

Atkinson, G.M. and Boore, D.M. (2003). Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions. *Bull. Seism. Soc. Am.*, 93, 1703–1729.
Atkinson, G.M. and Boore, D.M. (2011). Modifications to Existing Ground-Motion Prediction Equations in Light of New Data. *Bull.Seism.Soc.Am.* 101, 1121-1135; *doi:10.1785/0120100270.*
Bindi, D., Pacor, F., Luzi, L., Puglia, R., Massa, M., Ameri, G., Paolucci, R. (2011). Ground motion prediction equations derived from the Italian strong motion database. *Bull. Earthquake Eng.*, DOI 10.1007/s10518-011-9313-z.
Boore, D.M. and Atkinson, G.M. (2008). Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods Between 0.01 s and 10.0 s. Earthquake Spectra, 24, 99-138.
Cauzzi, C. and Faccioli, E. (2008). Broadband (0.05 s to 20 s) prediction of displacement response spectra based on worldwide digital records. Journal of Seismology, 12, 453-475.
Cornell, C.A. (1968). Engineering seismic risk analysis, *Bull. Seism. Soc. Am.,* 58, 1583-1606.
Cotton, F., Pousse, G., Bonilla, F. and Scherbaum, F. (2008). On the discrepancy of recent European ground-motion observations and predictions from empirical models: Analysis of KiK-net accelerometric data and point-source stochastic simulations. *Bull.Seism.Soc.Am.,* 98, 2244–2261.
García-Mayordomo, J., Martínez-Díaz, J.J., Capote, R., Martín-Banda, R., Insua-Arévalo, J.M., Álvarez-Gómez, J.A., Perea, H., González, A., Lafuente, P., Martín-González, F., Pérez-López, R., Rodríguez-Pascua, M.A., Giner-Robles, J., Azañón, J.M., Masana, E., Moreno, X., Benito, B., Rivas, A., Gaspar-Escribano, J.G., Cabañas, L., Vilanova, S., Fonseca, J., Nemser, E., Baize, S. (2012a). Modelo de Zonas Sismogénicas para el Cálculo de la Peligrosidad Sísmica en España. 7ª Asamblea Hispano Portuguesa de Geodesia y Geofísica. Donostia 2012.
ISO/IEC 98:1993. *Guide to the expression of uncertainty in measurement (GUM)*
Scherbaum, F., Cotton, F. and Smit, P. (2004). On the use of response spectral-reference data for the selection of ground-motion models for seismic hazard analysis: the case of rock motion. *Bull.Seism.Soc.Am.**94***, 2164-2185.
Tapia, M.M. (2006). *Desarrollo y aplicación de métodos avanzados para la caracterización de la respuesta sísmica del suelo a escala regional y local*. PhD Thesis. Universitat Politècnica de Catalunya, Barcelona, pp 356.
Youngs, R.R., Chiou, S.J., Silva, W.J., and Humphrey, J.R. (1997). Strong ground motion attenuation relationships for subduction zone earthquakes, *Seism. Res. Lett.* 68, 58–73.
Zhao, J. X., Zhang, J., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., Ogawa, H., Irikura, K. Thio, H. K., Somerville, P. G., Fukushima, Y., Fukushima, Y. (2006). Attenuation Relations of Strong Ground Motion in Japan Using Site Classification Based on Predominant Period. *Bull. Seism. Soc. Am.,* 96, 898-913. *doi: 10.1785/0120050122*